# NS 102 Lecture 9

Pieter Bruegel the Elder, ca. 1563

# The Well Tempered Cosmology Class

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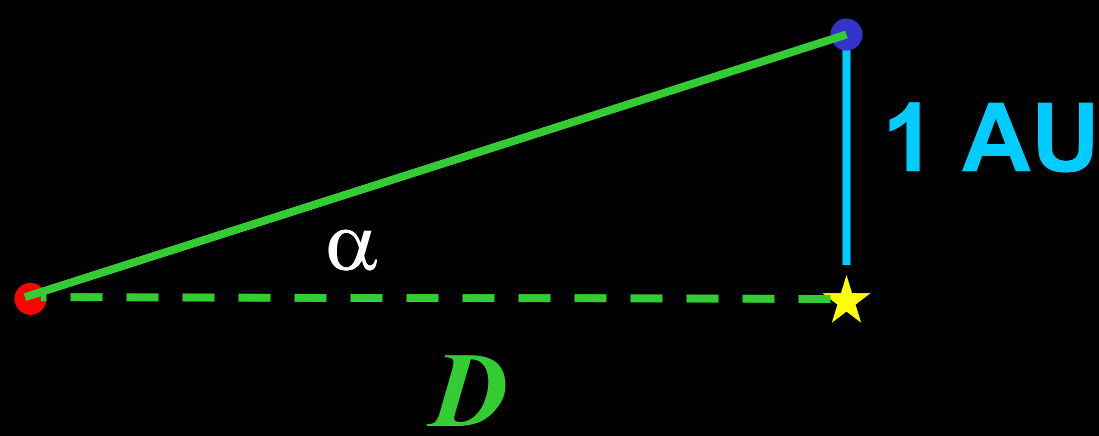
Pieter Bruegel the Elder, ca. 1563

# The Cosmological Distance Scale

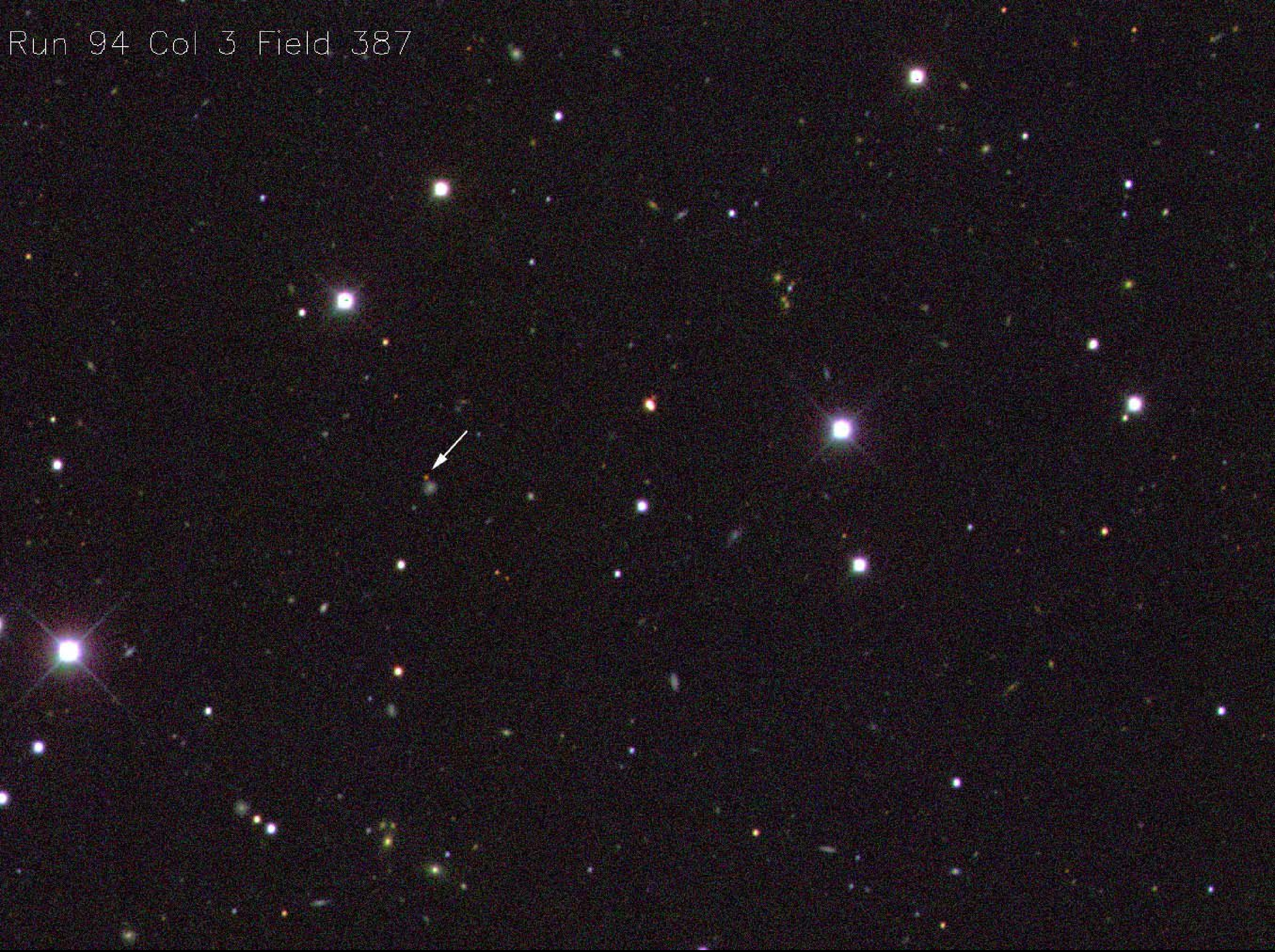
$$\frac{D}{200{,}000 \text{ AU}} = \frac{\text{seconds}}{\text{parallax}}$$

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$



$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$

| star | parallax (") | distance (pc) |
|---|---|---|
| $\alpha$ Centauri | 0.75 | 1.3 |
| Barnard's star | 0.5 | 2.0 |
| Sirius | 0.4 | 2.5 |
| Altair | 0.2 | 5.0 |


Run 94 Col 3 Field 387

They have different apparent brightness
They have different colors
They move
They change in brightness

# Intensity:  energy per time per area

$$I = \frac{\text{Energy}}{\text{Time Area}}$$

$I_0$ = threshold of hearing

$$dB = 10 \log (I/ I_0)$$

# Intensity: energy per time per area

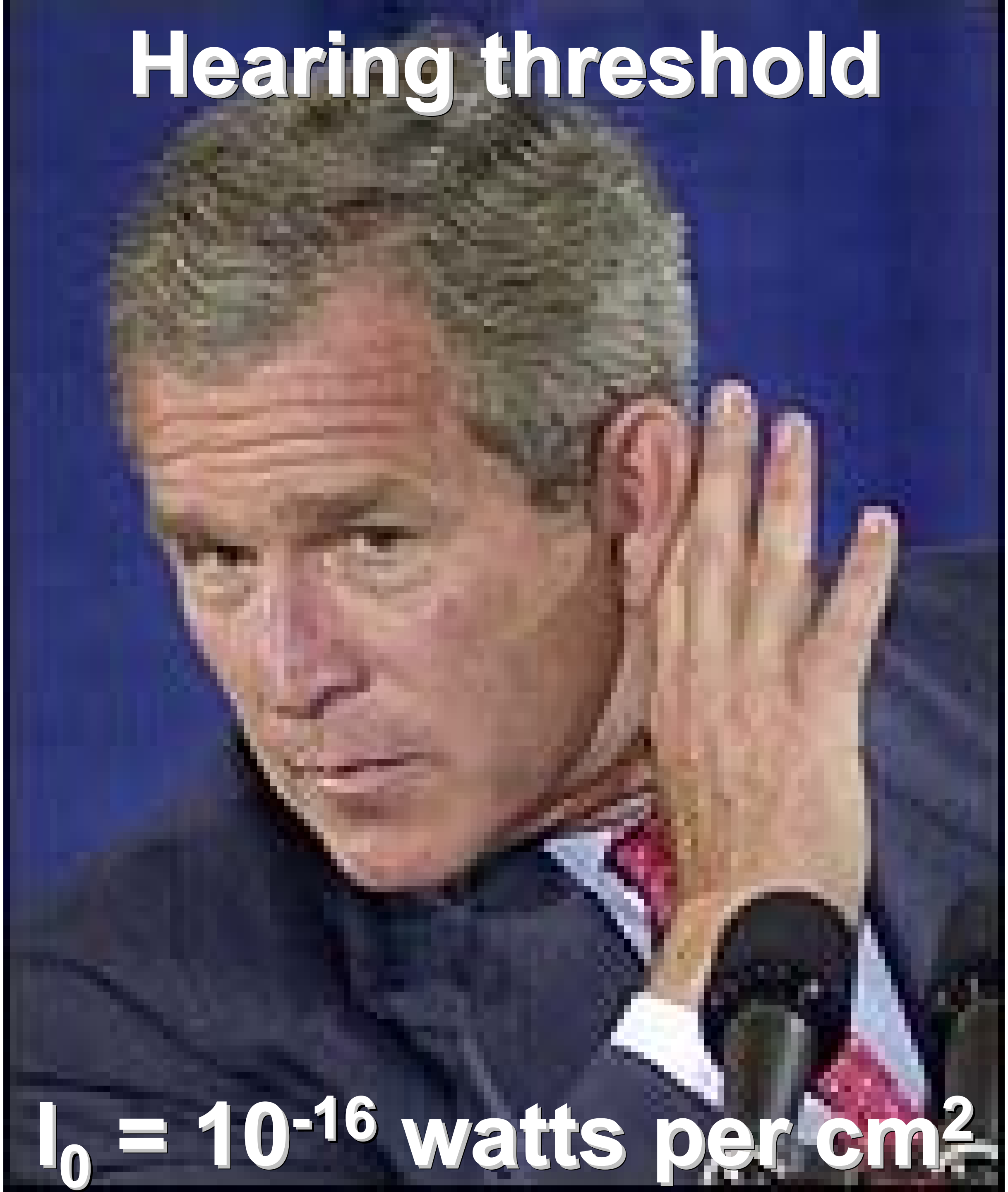
$$I = \frac{\text{Energy}}{\text{Time Area}}$$

$\frac{\text{Energy}}{\text{Time}}$ (Power) measured in watts

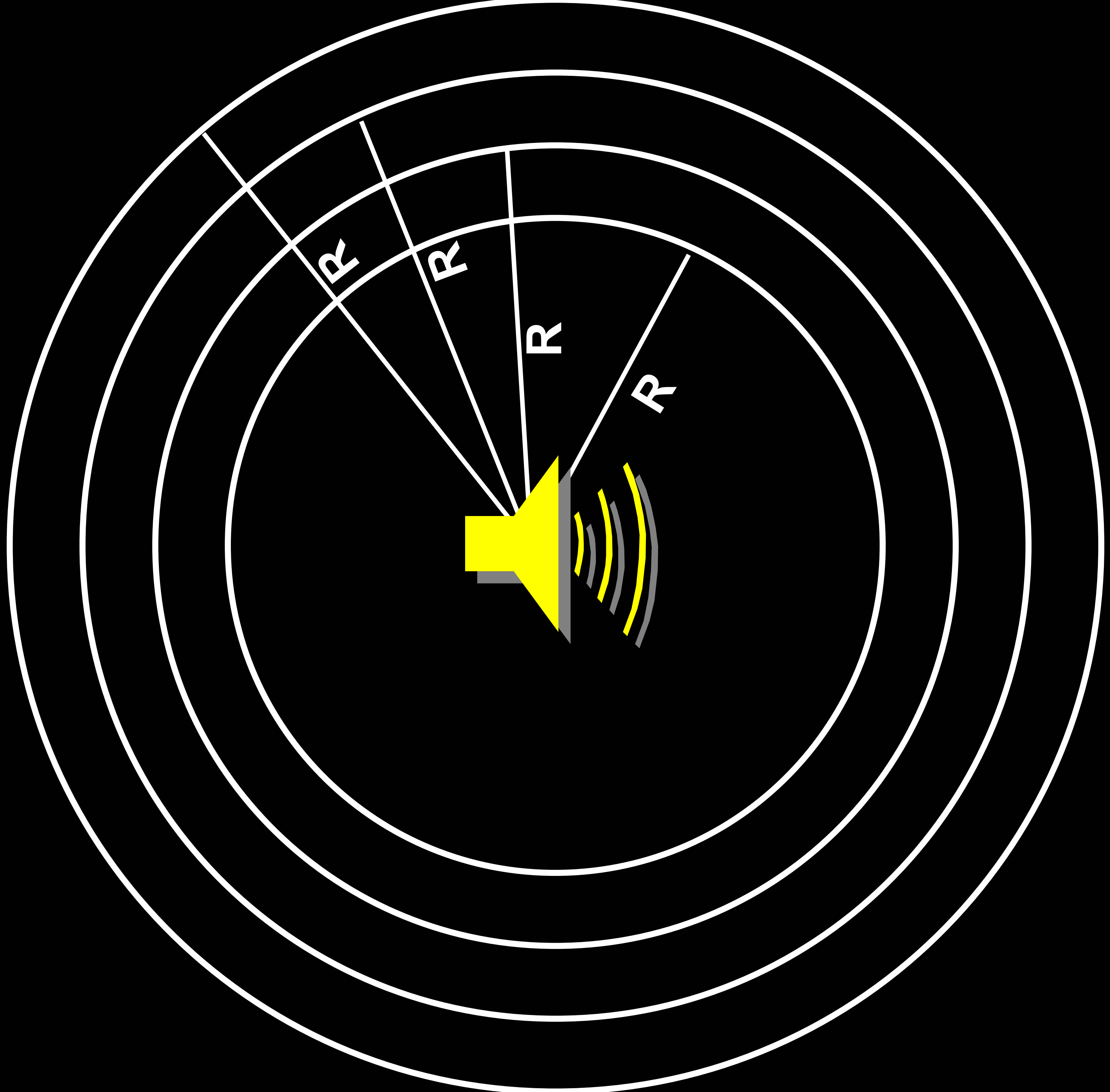
Area measured in $cm^2$

**Intensity in watts per $cm^2$**

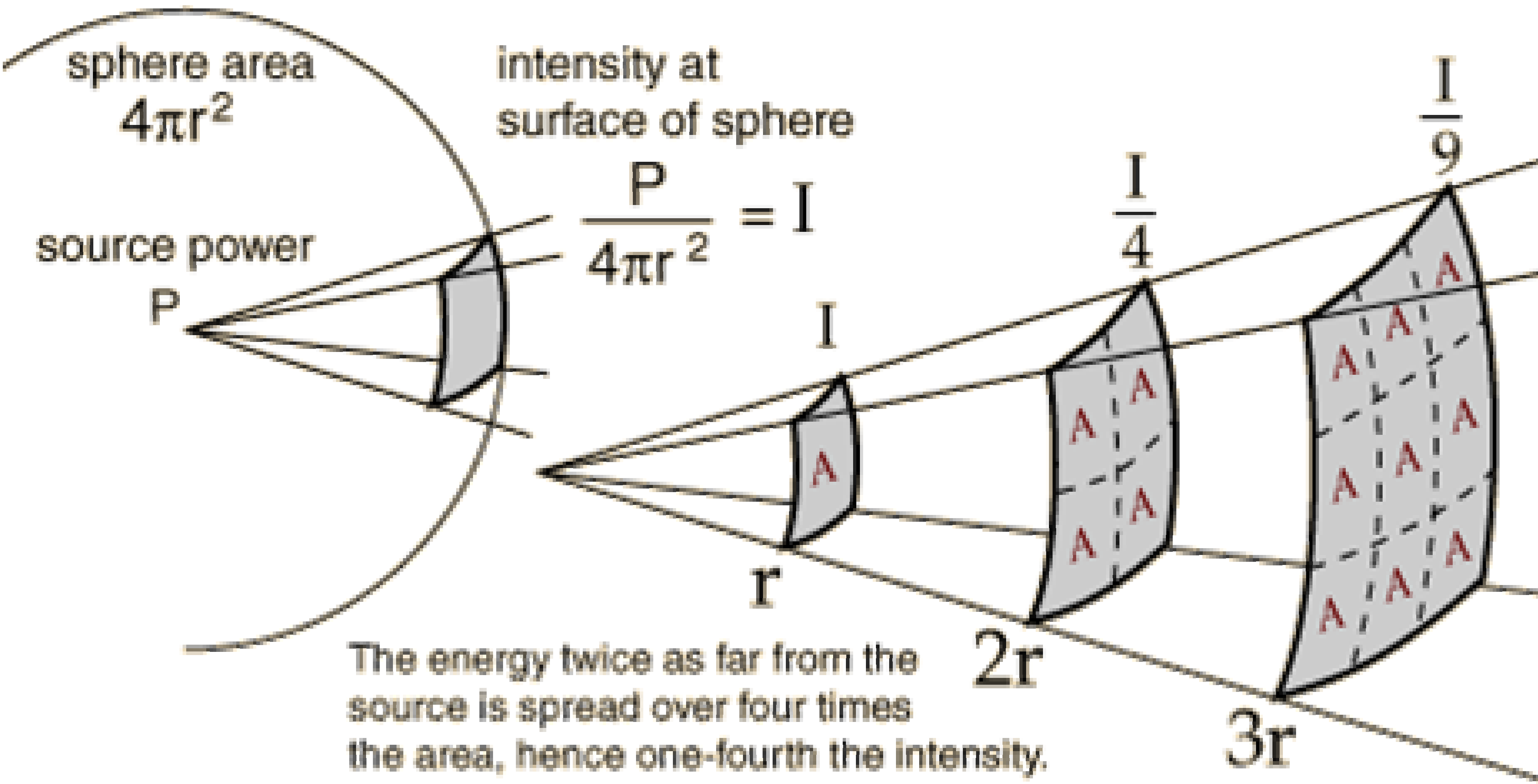
# Hearing threshold

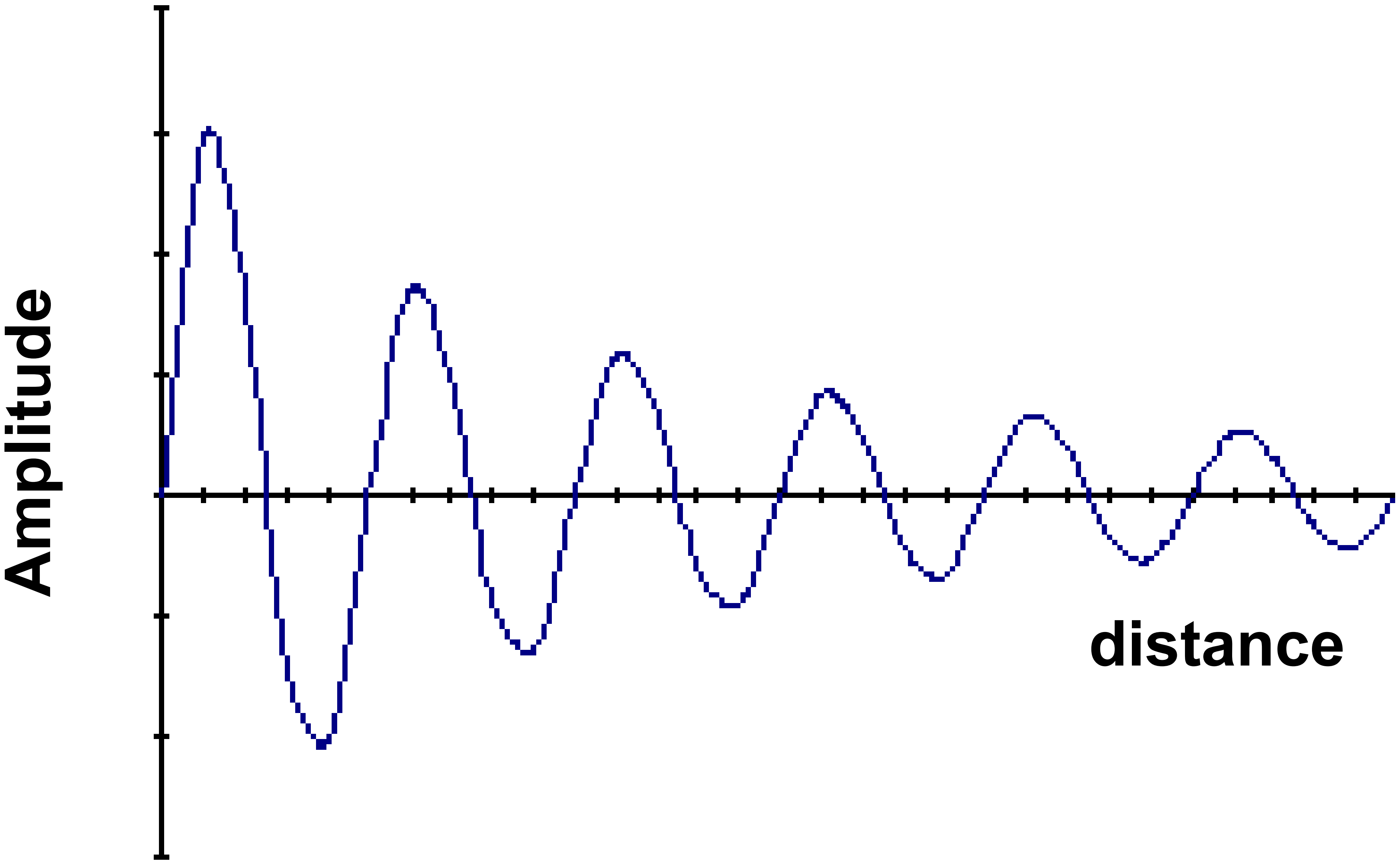


$I_0 = 10^{-16}$ watts per $cm^2$


R
R
R
R

# Inverse-square law




Amplitude
distance

# Intensity: energy per time per area

$$I = \frac{\text{Energy}}{\text{Time Area}} \qquad I = \frac{\text{power}}{\text{cm}^2}$$

Power — property of source

Intensity — depends on power and distance between source and detector (R)

$$\text{Intensity} = \frac{\text{power}}{4\pi R^2}$$

# Let there be light

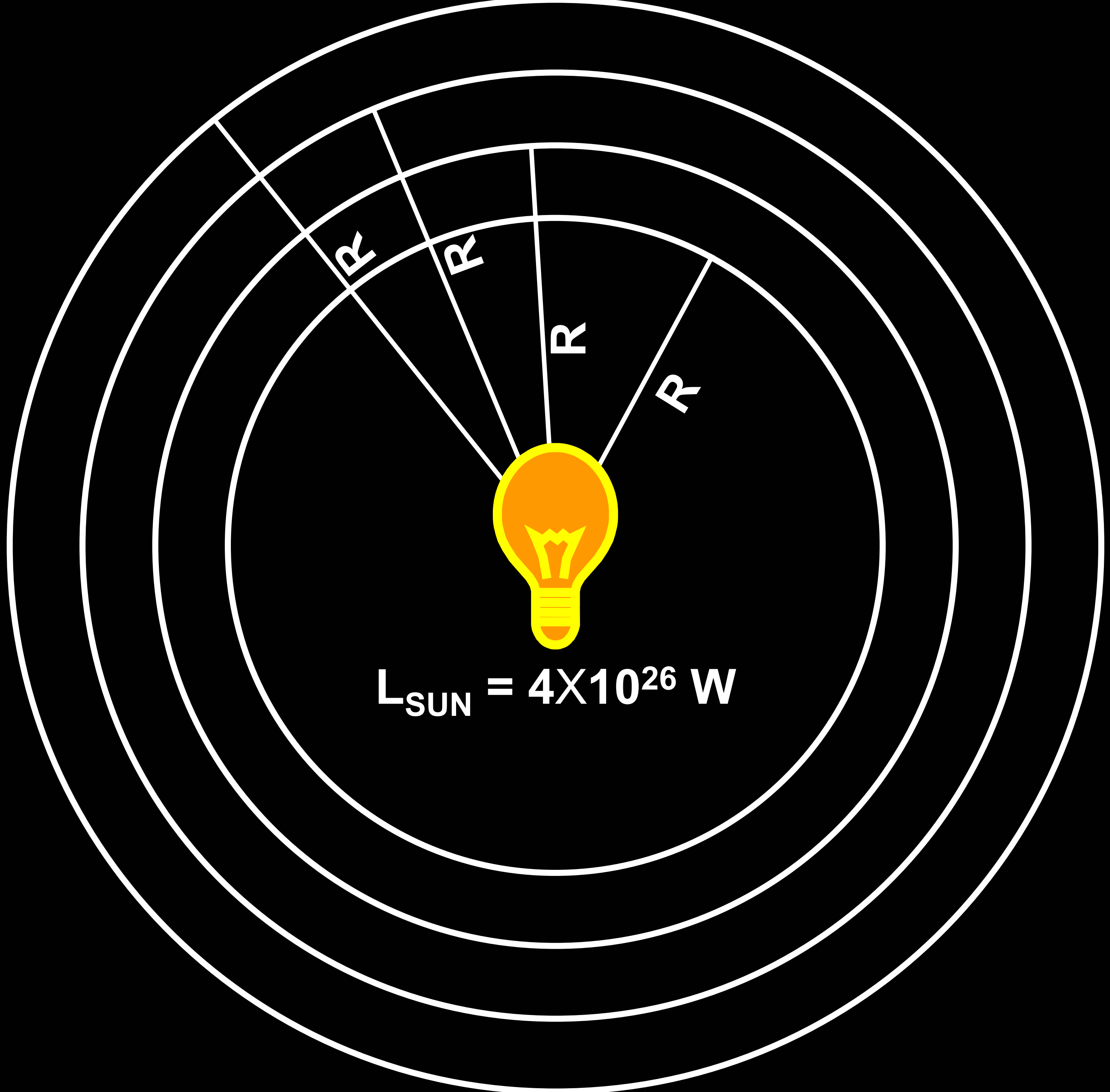
# ***For light!!!***

$$I = \frac{\text{Energy}}{\text{Time Area}}$$

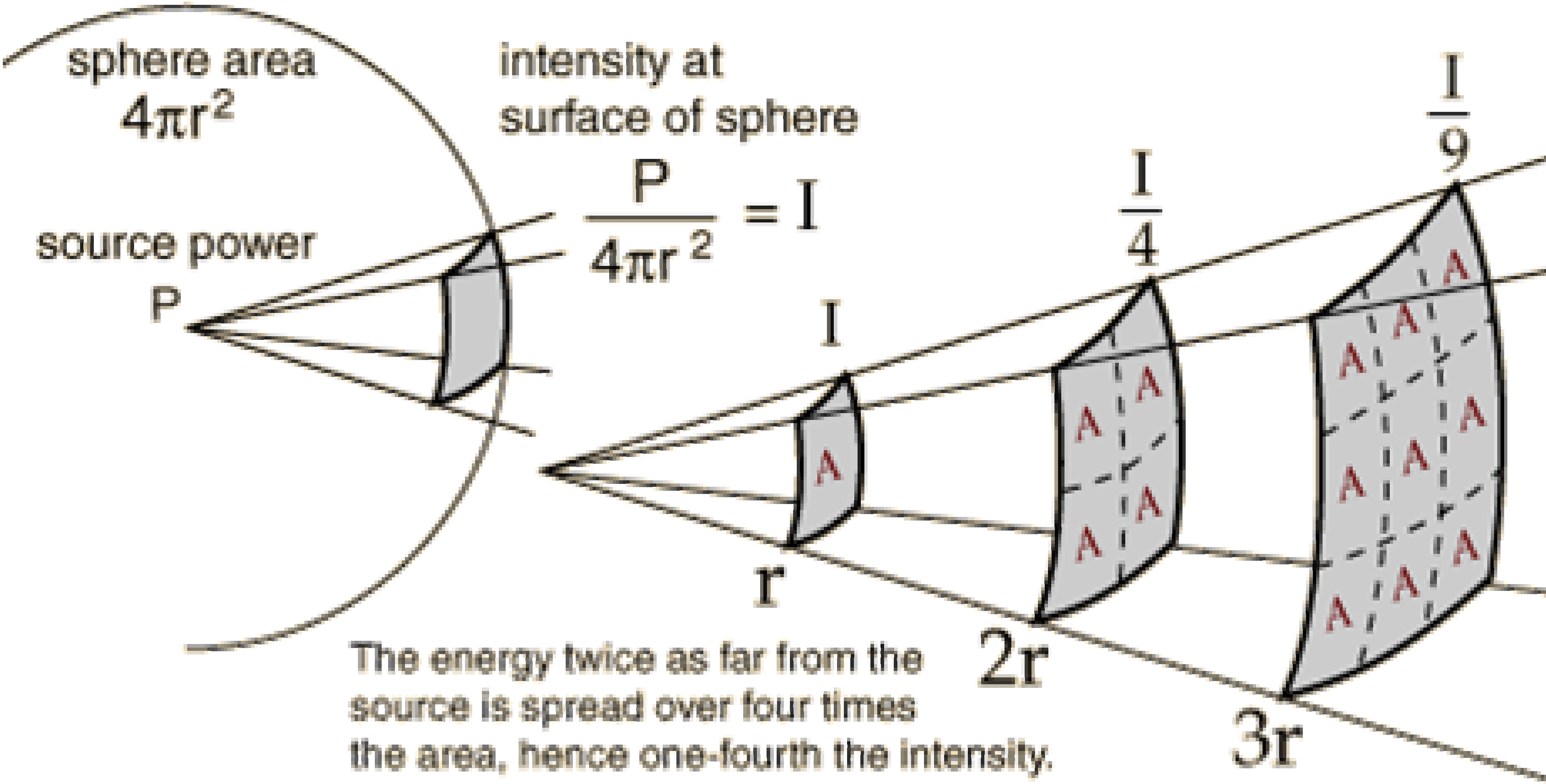
$\frac{\text{Energy}}{\text{Time}}$ (Luminosity) measured in watts

Area measured in $cm^2$

**Intensity in watts per $cm^2$**


R
R
R
R
$L_{SUN} = 4 \times 10^{26}$ W

# Inverse-square law



# For light!!!

$$I = \frac{\text{luminosity}}{\text{cm}^2}$$

**Luminosity** property of source

**Intensity** depends on power and distance between source and detector (R)

$$\text{Intensity} = \frac{\text{luminosity}}{4\pi R^2}$$

# LET THERE BE LIGHT!

**Greeks classified stars into 6 classes, or <u>magnitudes</u>**

**Brightest stars were 1st magnitude**
**Dimmest stars were 6th magnitude**

**Intensity of brightest stars = 100 X dimmest.**

# Logarithmic Eye

**Eyes, like ears, are logarithmetic detectors.**

**For sound:** $\mathrm{dB}_1 - \mathrm{dB}_2 = \alpha \log\left(I_1/I_2\right)$

**To define scale, need 3 numbers for reference:** $\alpha$, $\mathrm{dB}_0$, and $I_0$

**At threshold of hearing:** $\mathrm{dB}_0 = 0$ and $I = I_0$

$$\mathrm{dB} = \alpha \log\left(I/I_0\right)$$

**At threshold of pain:** $\mathrm{dB} = 120$ and $I = 10^{12} I_0$

$$120 = \alpha \log\left(10^{12}\right)$$

$$\boxed{\mathrm{dB} = 10 \log\left(I/I_0\right)}$$

**For sound:** $$\mathrm{dB}_1 - \mathrm{dB}_2 = 10 \log\left(I_1 / I_2\right)$$

**For light:** $$m_1 - m_2 = \alpha \log\left(I_1 / I_2\right)$$

$$1 - 6 = \alpha \log\left(10^2\right)$$

$$-5/2 = \alpha$$

$$\alpha = -2.5$$

$$\boxed{m_1 - m_2 = -2.5 \log\left(I_1 / I_2\right)}$$

**"–" means smaller $m$ is brighter!**

**For light:** $$m_1 - m_2 = -2.5\log\left(I_1/I_2\right)$$

**Need to define the scale:**

$$I_\odot = 0.137 \text{ watts cm}^{-2}$$

$$m_\odot = -26.8$$

**For source of intensity I, the magnitude is**

$$-26.8 - m = -2.5\log\left(0.137 \text{ watts cm}^{-2}/I\right)$$

**"–" means smaller *m* is brighter!**

# Some Magnitudes

| | |
|---|---|
| Sun | $m = -26.8$ |
| Venus | $m = -4$ |
| Sirius | $m = -1.5$ |
| Naked eye limit | $m = 6$ |
| Binoculars | $m = 10$ |
| Pluto | $m = 15$ |
| Large telescope (visual) | $m = 20$ |
| Large telescope (photograph) | $m = 25$ |
| Large telescope (ccd) | $m = 30$ |

# Intensity of sun vs. naked eye limit

Sun $m_S = -26.8$

Naked eye limit $m_N = 6$

$$m_S - m_N = -2.5 \log(I_S/I_N)$$

$$-27 - 6 = -2.5 \log(I_S/I_N)$$

$$\cancel{-}33 = \cancel{-}\frac{5}{2} \log(I_S/I_N)$$

$$33 \times \frac{2}{5} = 13 = \log(I_S/I_N)$$

$$10^{13} = I_S/I_N$$

# Intensity of Venus vs. Pluto

**Venus** $m_{♀} = -4$

**Pluto** $m_p = 15$

$$m_{♀} - m_P = -2.5 \log(I_{♀}/I_P)$$

$$-4 - 15 = -2.5 \log(I_{♀}/I_P)$$

$$\cancel{-}19 = \cancel{-}\frac{5}{2} \log(I_{♀}/I_P)$$

$$19 \times \frac{2}{5} = 8 = \log(I_{♀}/I_P)$$

$$10^8 = I_{♀}/I_P$$

# Intensity of Venus vs. Sirius

Venus $m_{♀} = -4$

Sirius $m_S = -1.5$

$$m_{♀} - m_S = -2.5 \log(I_{♀}/I_S)$$

$$-4 - (-1.5) = -2.5 \log(I_{♀}/I_S)$$

$$\cancel{-}2.5 = \cancel{-}2.5 \log(I_{♀}/I_S)$$

$$1 = \log(I_{♀}/I_S)$$

$$10^1 = 10 = I_{♀}/I_S$$

# The luminosity of nearby stars?

**Measure: intensity of light, I**

**parallax → distance**

$$I = \frac{L}{4\pi R^2}$$

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}}$$

$$I = \frac{L}{4\pi R^2}$$

$$-26.8 - m = -2.5 \log\left(0.137 \text{ watts cm}^{-2} / I\right)$$

**Measured**

| star | parallax (”) | distance (pc) | apparent magnitude | luminosity (solar) |
|---|---|---|---|---|
| $\alpha$ Centauri | 0.75 | 1.3 | 0 | 1.5 |
| Barnard’s star | 0.5 | 2.0 | 9.5 | 0.0005 |
| Sirius | 0.4 | 2.5 | -1.5 | 25 |
| Altair | 0.2 | 5.0 | 0.8 | 10 |
| Canopus | 0.003 | 330 | - 0.7 | 200,000 |
| Arcturus | 0.1 | 10 | 0 | 90 |
| Betelgeuse | 0.01 | 100 | 0.5 | 14,000 |

# Intensity of Sun vs. Sirius

Sun $m_S = -26.8$

Sirius $m_I = -1.5$

$$m_S - m_I = -2.5 \log(I_S/I_I)$$

$$10^{10} = I_S/I_I$$

We know the distance to Sirius via parallax

Parallax = 0.4 second

Distance = (1/parallax) pc = 2.5 pc = 2.5 X 200,000 AU
= 500,000 AU

# Our Sun ain't the brightest bulb in the box!

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

$$L_{SIRIUS} = 25 \times L_{SUN}$$

For stars we know distance to via parallax:

Measure Distance (R)
Measure Intensity

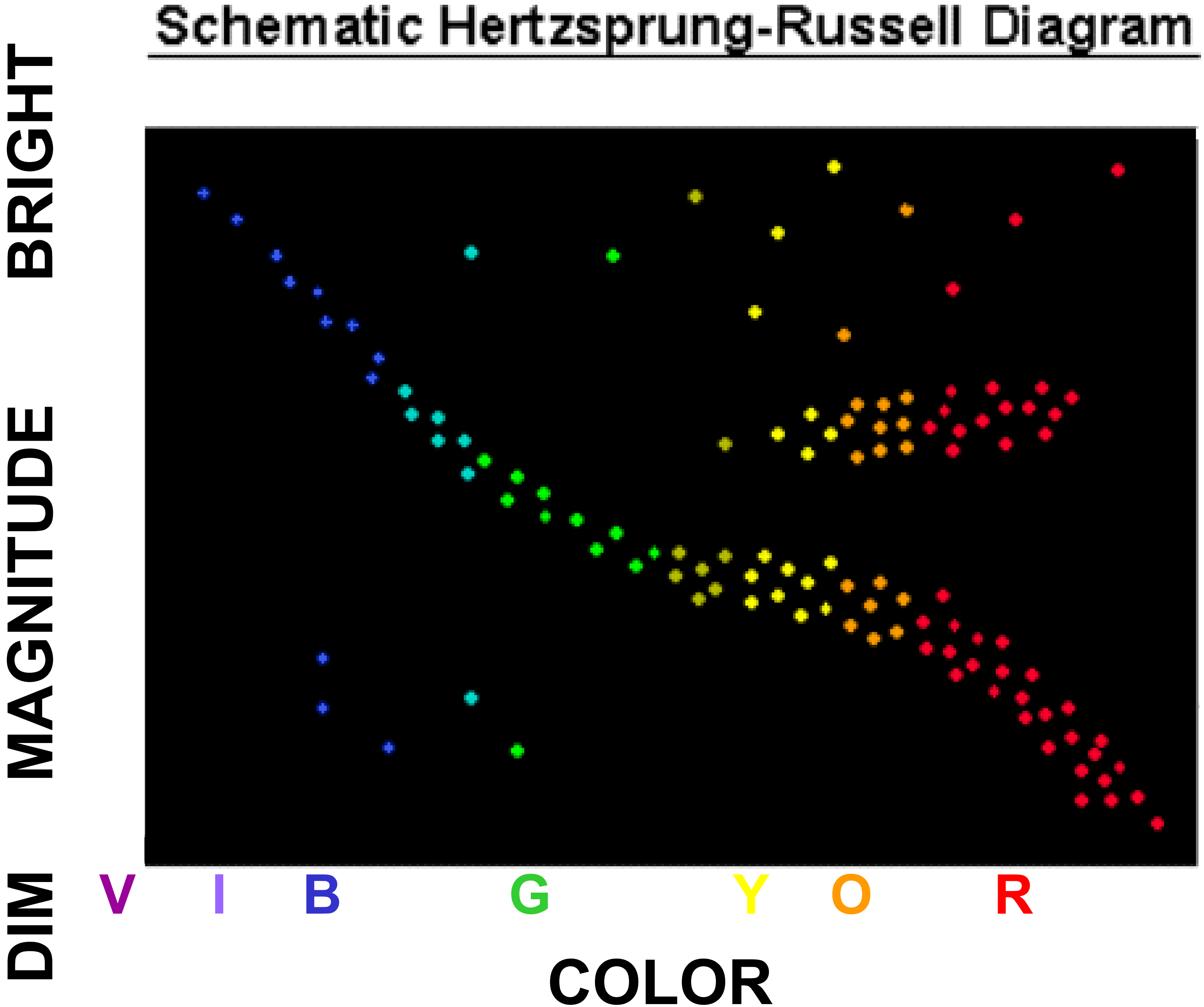
$\longrightarrow$ Know Luminosity

**They have different apparent brightness**
**They have different colors**
**They move**
**They change in brightness**

**COLORS OF THE RAINBOW:**

**R O Y – G – B I V**

Open Cluster (The Pleiades)
130 pc distant


Schematic Hertzsprung-Russell Diagram
BRIGHT
MAGNITUDE
DIM
V
I
B
G
Y
O
R
COLOR